FFI Forsvarets forskningsinstitutt

ITU-R Working Party 5B

AIS Modeling and a Satellite for AIS Observations in the High North

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Draft New ITU-R Report "Improved Satellite Detection of AIS"

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Draft New Report

"Improved Satellite Detection of AIS"

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- Solving the problem of overlapping messages (blurred reception)
- Solving the problem of the large number of messages in the satellite antenna footprint
- Operating frequencies for satellite detection of AIS

Contributions From FFI (Presentation to RTCM 2008)

- Short overview of the space-based AIS challenge
- Updated global detection probability modeling for “AIS as is”
- Norwegian satellite for AIS observations in the High North
- Latest global detection probability modeling for a “3rd AIS channel”

Basic technical limitations addressed by Draft New ITU-R Report (2008)

Report ITU-R M.2084 (2006) “Satellite detection of automatic identification system messages” proposed further studies to deal with the technical limitations that hinder detection of AIS-equipped target ships in high-traffic areas (e.g. the Dover Straits, Singapore, North East United States, and the northern Gulf of Mexico) on the designated AIS VDL (VHF Data Link). The technical limitations specifically cited were:

1) the length of the AIS message in the time slot (insufficient time buffer for the satellite detection range);
2) the large number of messages in the satellite antenna footprint (excess re-use of the time slots in the VDL as detected by the satellite);
3) the difficulty Satellite AIS has in distinguishing signals between AIS messages and communications from terrestrial services within the satellite antenna footprint (coverage pattern).

Solving the problem of overlapping messages (blurred reception)

Default AIS data packet bit structure

Power ramp up	8 bits	
Training sequence	24 bits	Necessary for synchronization
Start flag	8 bits	
Data field	168 bits	Default length
Cyclic redundancy code	16 bits	Necessary for error detection
End flag	8 bits	
Buffer	24 bits (typically, the last 20-bit positions are empty)	Allowance for bit stuffing, propagation delay, repeater delay, and jitter. **NOTE: Propagation buffer (12 bits) provides up to 208 NM for SAR aircraft and AIS Base stations.**
Total	256 bits	

Solving the problem of overlapping messages (blurred reception)

AIS satellite propagation calculations

Constants:			
Speed of light (metres/sec)	299792458		
AIS bit-time @ 9600 bps (milliseconds)	0.1041667		
Nautical mile (km per nm)	1.852		
Calculations:	**Orbit #1**	**Orbit #2**	**Orbit #3**
Satellite orbital altitude (km/nm)	600/324	948/512	1000/540
Slant range to horizon (km/nm)	2831/1529	3604/1946	3709/2003
Ground range to horizon (km/nm)	2664/1438	3281/1772	3359/1814
Difference in propagation distance (km/nm)	2231/1205	2656/1434	2709/1463
Propagation time delay difference (milliseconds)	7.44	8.86	9.04
Propagation time delay difference (bits)	**71**	**85**	**87**
Typical satellite visibility (minutes)[1]	10.2	13.6	14.0

[1] These satellite visibility periods are for a typical overhead pass of the satellite based on a circular, polar-orbiting satellite for the indicated satellite altitudes and a target ship located at 40º Latitude. Typical visibility periods will vary depending on a number of factors including satellite inclination angle and target ship latitude.

Solving the problem of overlapping messages (blurred reception)

Modified AIS packet bit structure for satellite reception

Slot composition	Bits	Notes
Ramp up	8	Standard
Training sequence	24	Standard
Start flag	8	Standard
Data field	96	Data field is 168 bits for other single-slot messages. This field is shortened by 72 bits to support the satellite AIS system buffer.
CRC	16	Standard
End flag	8	Standard
Satellite AIS system buffer	96	Bit stuffing = 4 bits Synch jitter (mobile station) = 3 bits ~~Synch jitter (mobile/satellite) = 1 bit~~ **Propagation time delay difference = 87 bits** Spare = 1 bit
Total	256	Standard **(NOTE – Only 160 bits are used in the 17 millisecond transmission)**

Solving the problem of overlapping messages (blurred reception)

Proposed new data field for AIS satellite detection Message 27

Parameter	Number of bits	Description
Message ID	6	Identifier for this message (similar to all other messages)
Repeat indicator	2	Repeat indicator value should be 3
User ID	30	MMSI number
Position accuracy	1	As defined for Message 1
RAIM Flag	1	As defined for Message 1
Navigational status	4	As defined for Message 1
Longitude	18	Longitude in 1/10 min (±180º, East = positive, West = negative
Latitude	17	Latitude in 1/10 min (±90º, North = positive, South = negative
SOG	6	Knots (0-62); 63 = not available = default
COG	9	Degrees (0-359); 511 = not available = default
Status of current GNSS position	1	0 = Position is the current GNSS position; 1 = Reported position is not the current GNSS position = default
Spare	1	Set to zero, to preserve byte boundaries
Total	**96**	

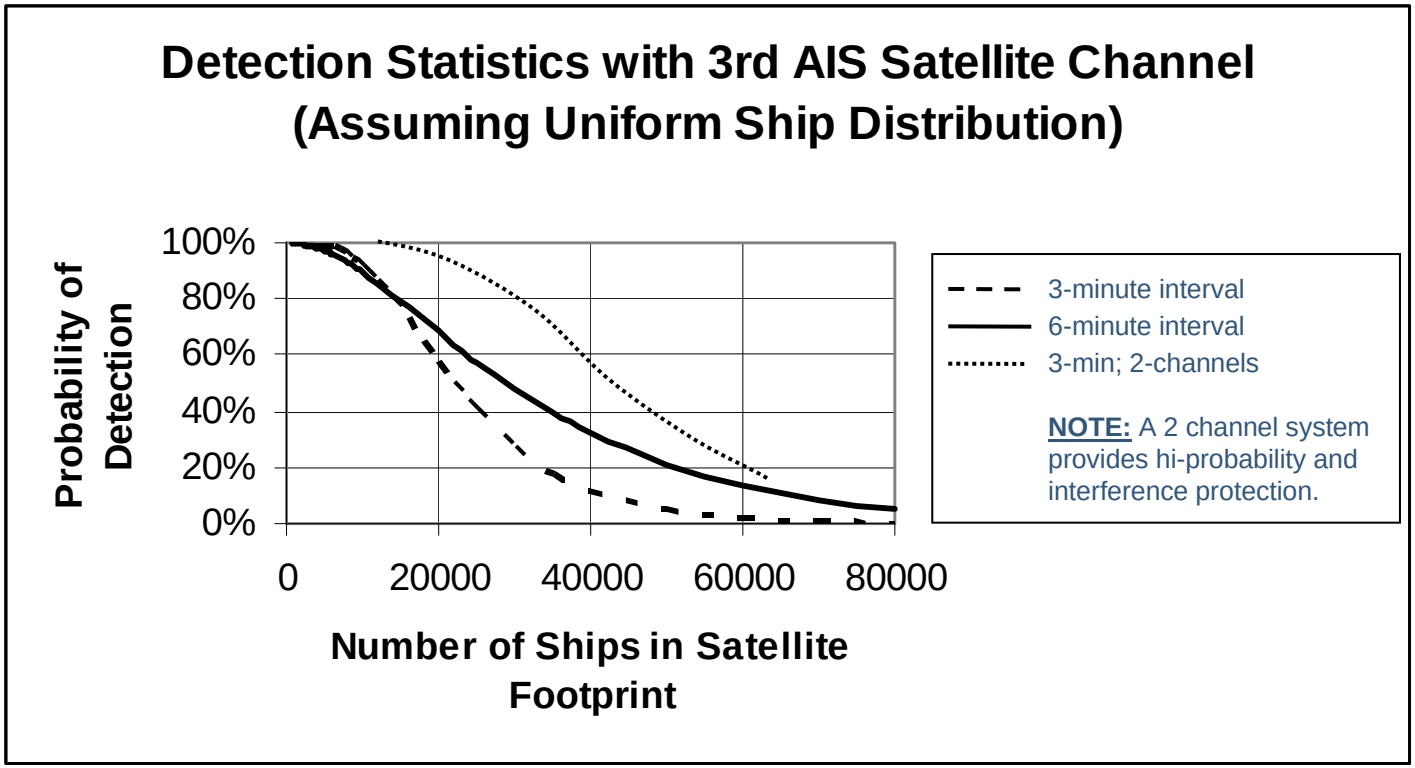
Solving the problem of the large number of messages in the satellite antenna footprint

The large number of messages in the satellite antenna footprint (excess re-use of the time slots in the VDL as detected by the satellite) is attributable to both the large number of ships and the reporting rate. Studies show that 100% of AIS Class A ships can be detected if:

1) an appropriate reporting rate for the AIS Class A ships is selected (on separate frequencies);
2) coastal ships within range of an AIS base station are eliminated; and
3) the AIS Class B is eliminated from satellite reception (on the separate frequencies).

Solving the problem of the large number of messages in the satellite antenna footprint

Optimizing the reporting rate for AIS Class A ships



Assumptions:

1) Uniform ship distribution
2) Target ship located at 40 deg. latitude
3) 160 bit packet length (256 bits normal packet – 96 bits buffer for Message 27)
4) Polar orbiting satellite with 13.6 minutes average satellite visibility period.

Solving the problem of the large number of messages in the satellite antenna footprint

Eliminating coastal ships within range of an AIS base station

- AIS base stations transmit AIS Base Station Message 4.
- AIS base station coverage is to 50NM or more.
- Redundant shore/satellite AIS coverage is unnecessary.
- Therefore, it is proposed that when a ship receives an AIS Base Station Message 4, the ship should reset the 3-minute message timer for the proposed Message 27. This provision will greatly improve the probability of detection by reducing the number of reports.

Solving the problem of the large number of messages in the satellite antenna footprint

Eliminating the AIS Class B from the separate frequencies

- Simulation results indicate that both AIS Class A transmissions at 12.5 Watts and Class B “CS” transmissions at 2 Watts have sufficient signal margins to support satellite AIS reception.
- The satellite cannot provide of reception for the expected combined population of Classes A & B on the same frequencies.
- Some Administrations have stated the need, based on simulation results, for special frequencies for satellite AIS transmission.
- Since the shipborne AIS is not be required to receive on those frequencies, the message transmission could be by RATDMA based solely on the activity of AIS 1 and AIS 2.

Solving the problem of the large number of messages in the satellite antenna footprint

Operating frequencies for satellite detection of AIS

- Frequencies for satellite detection of AIS should consider that the AIS Class A is limited to Appendix 18. Class B can tune only a limited segment of this range.
- Report ITU-R M.2084 indicated a high interference environment from non-maritime services in the satellite antenna footprint covering both land and sea.
- Appendix 18 has only 3 frequencies (channels 16, 75 and 76) that are exclusively dedicated to maritime services on a global basis.
- Channels 75 and 76 are limited to 1 Watt for radio transmissions.
- AIS transmission at 12.5 Watts for 17 ms every 3 minutes would not interfere with voice communications (Draft New ITU-R Report provides a mathematical analysis and refers to www.navcen.uscg.gov/enav/ais/JSC-PR-04-007.pdf).
- These AIS transmission would be detectable over 1 Watt radio transmissions.

Summary Conclusions: Draft New ITU-R Report "Improved Satellite Detection of AIS"

This Report addresses the technical limitations cited in Report ITU-R M.2084 that invited further studies. The possible solutions reached herein are:

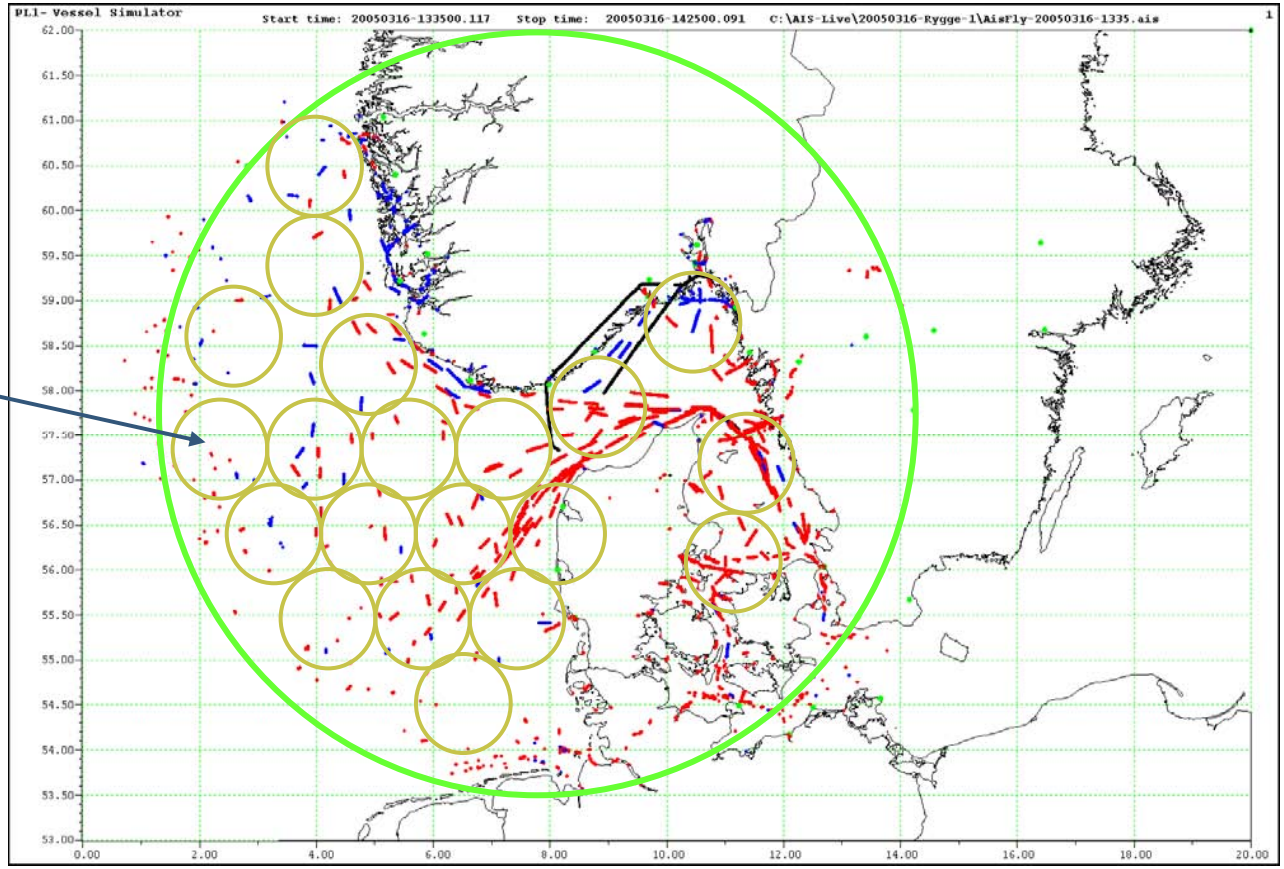
1) A special short AIS message (proposed Message 27, of only 96 bits) that is tailored for satellite reception would solve the problem of blurred reception.
2) A special reporting interval (proposed 3 minutes) is needed for the satellite AIS message.
3) Ships within range of an AIS base station should suppress transmission of this message.
4) Separate operating frequencies in addition to AIS 1 and AIS 2 are needed that are not subject to terrestrial use.
5) Frequencies should be considered only from Appendix 18 due to the limited tuning range of the shipborne AIS.

Summary Conclusions: Draft New ITU-R Report "Improved Satellite Detection of AIS"

6) Appendix 18 contains only 3 frequencies (channels 16, 75 and 76) that are exclusively dedicated to maritime use (channels 75 and 76 are proposed to be shared with this service). This proposal meets the intent of footnote *n)* to Appendix 18 for interference mitigation.
7) Satellite detection of the shipborne AIS should be limited to the AIS Class A (SOLAS Class) because the AIS Class B population is too large to be included.
8) Recommendation ITU-R M.1371-3 should be revised to add the proposed Message 27 along with its transmissions on the designated channels 75 and 76, and the AIS Class A equipment should be updated to add this message to facilitate improved satellite AIS detection.

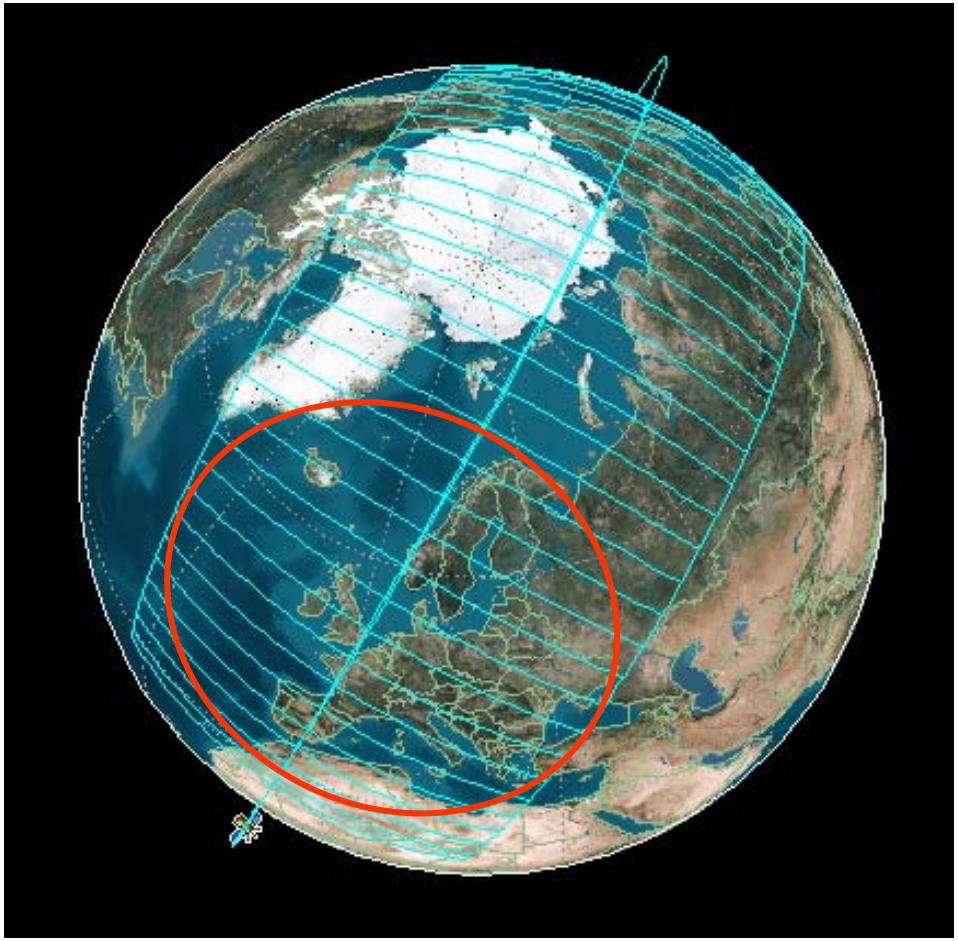
The Space-based AIS Challenge

Organized cells



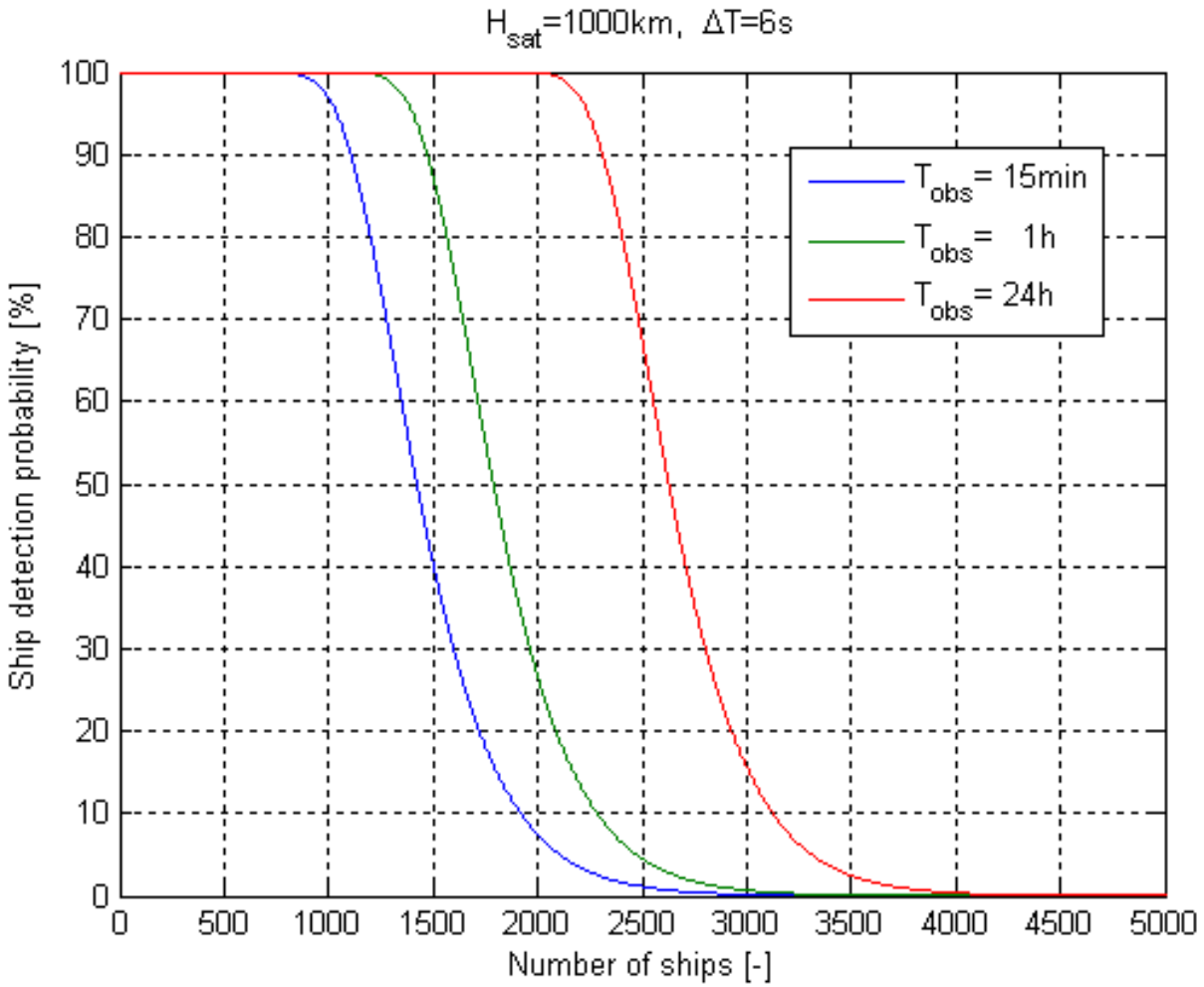
Simultaneous arrival of messages from several “organized cells" causes loss of messages

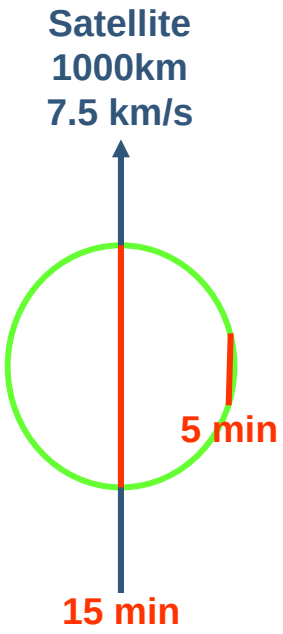
Field of View of a Satellite at 1000km



10000+ vessels within the field of view

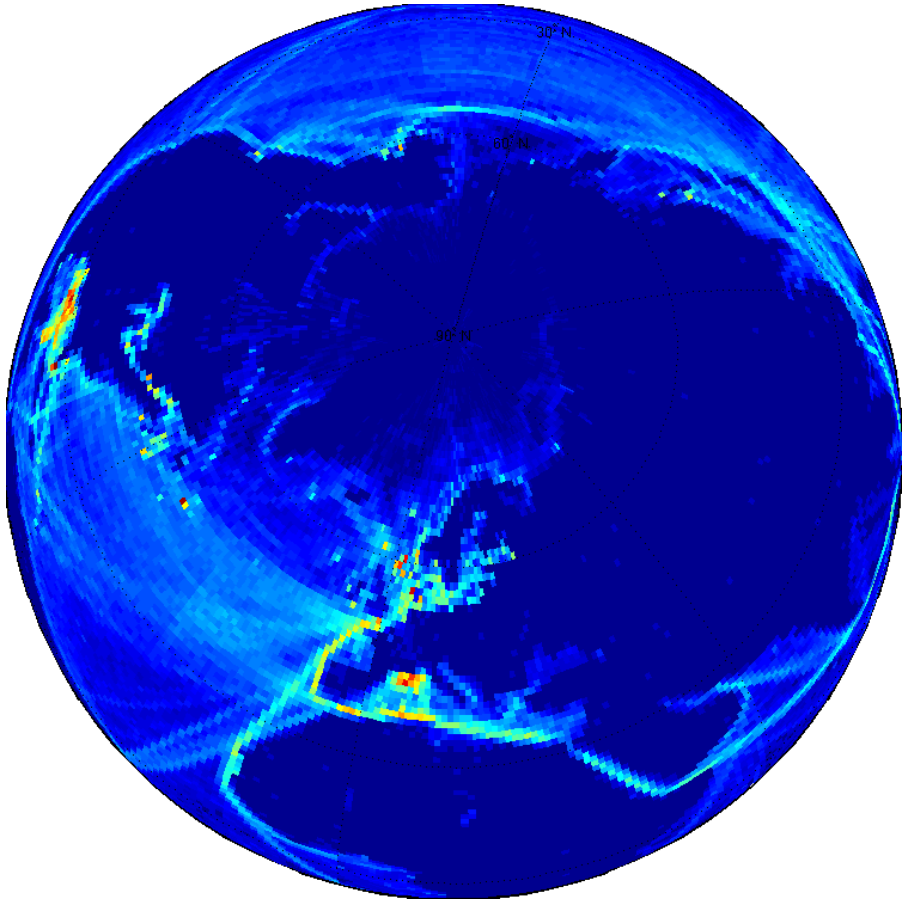
AIS Detection Probability - Satellite





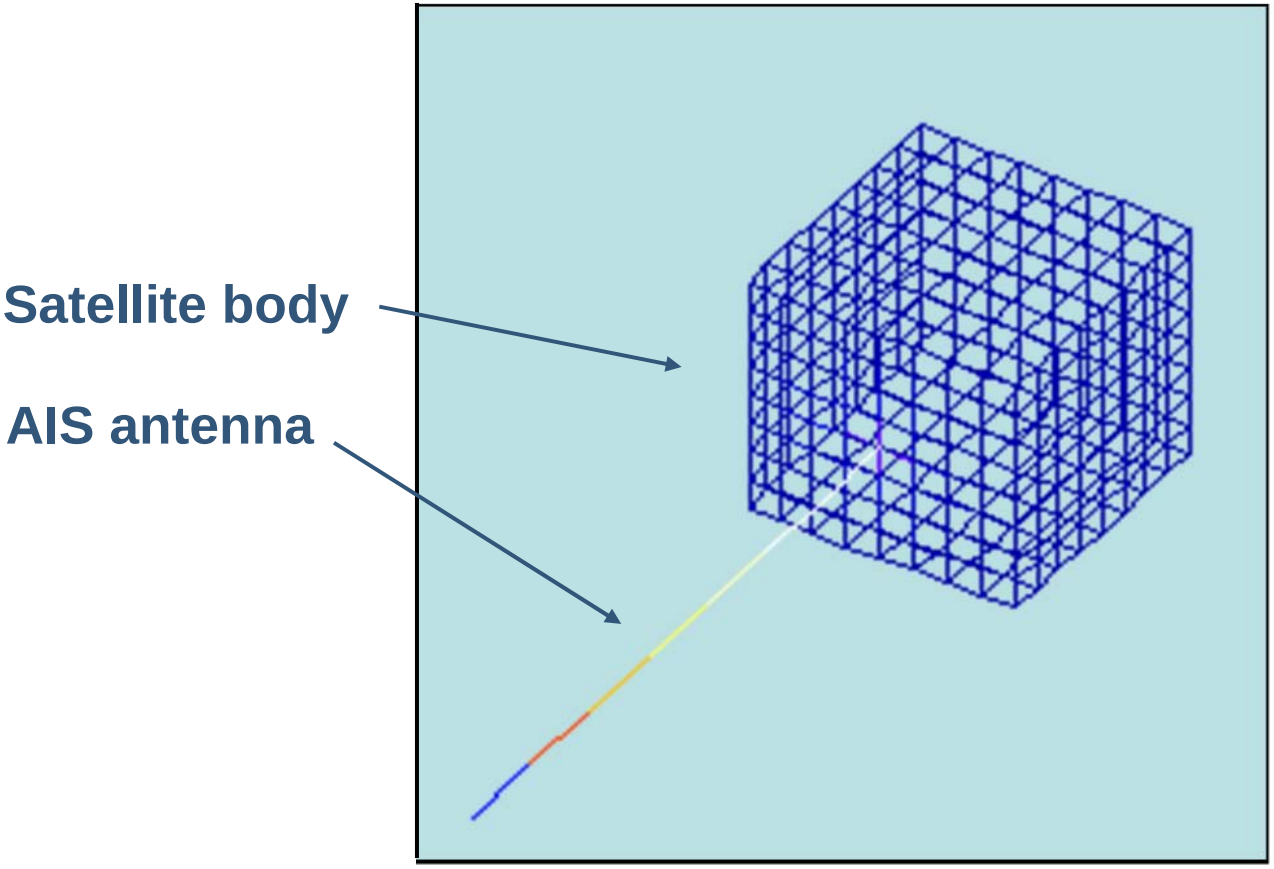
Simulation results for a swath width of 2880 nm (Type 1-3 messages)

Global AIS Vessel Distribution Map



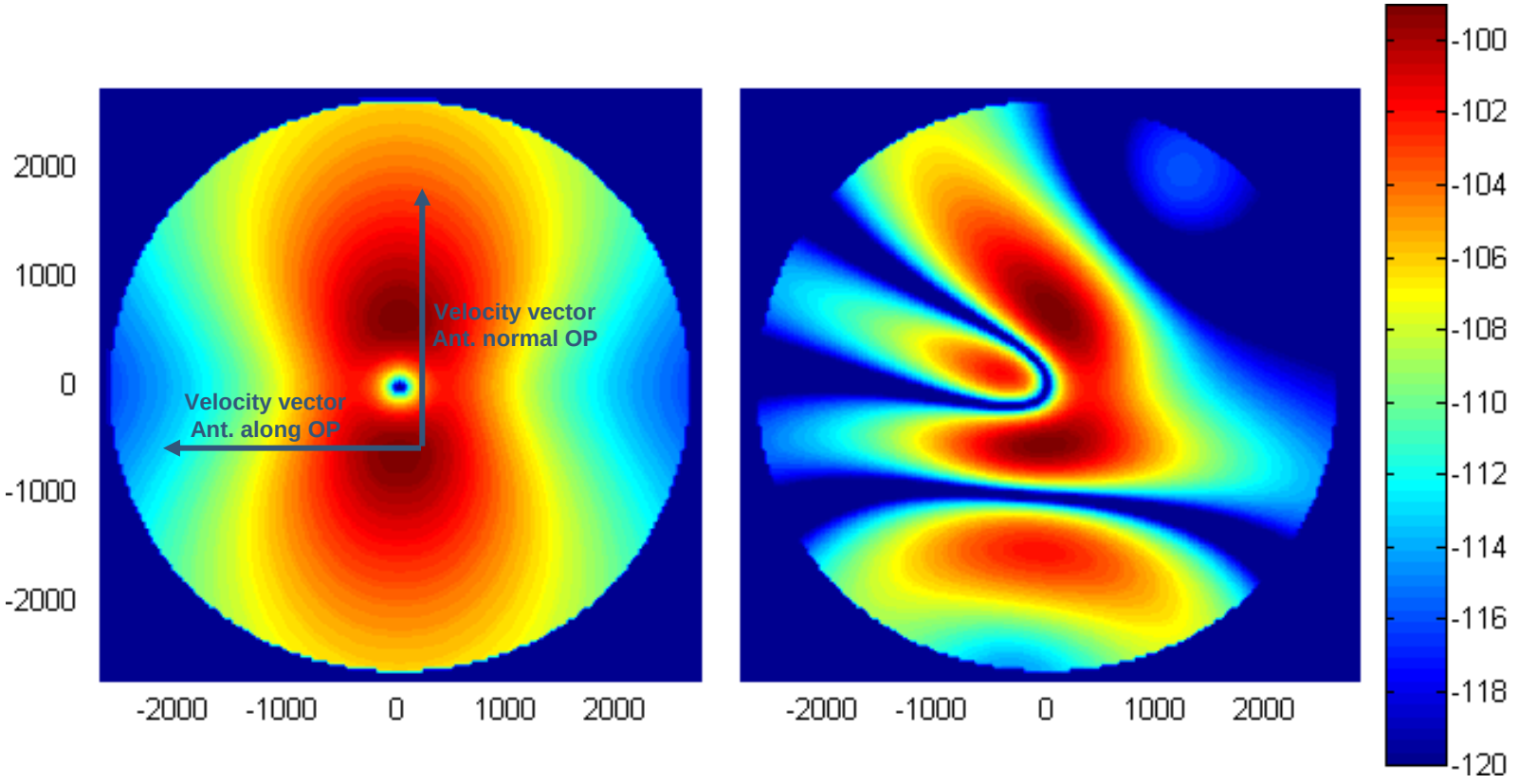
Taken from ICOADS and updated by observations
52000 moving vessels globally

Satellite model



AIS antenna length 46 cm, Satellite body 20x20x20cm

AIS Signal Power (dBm) at 600 km altitude

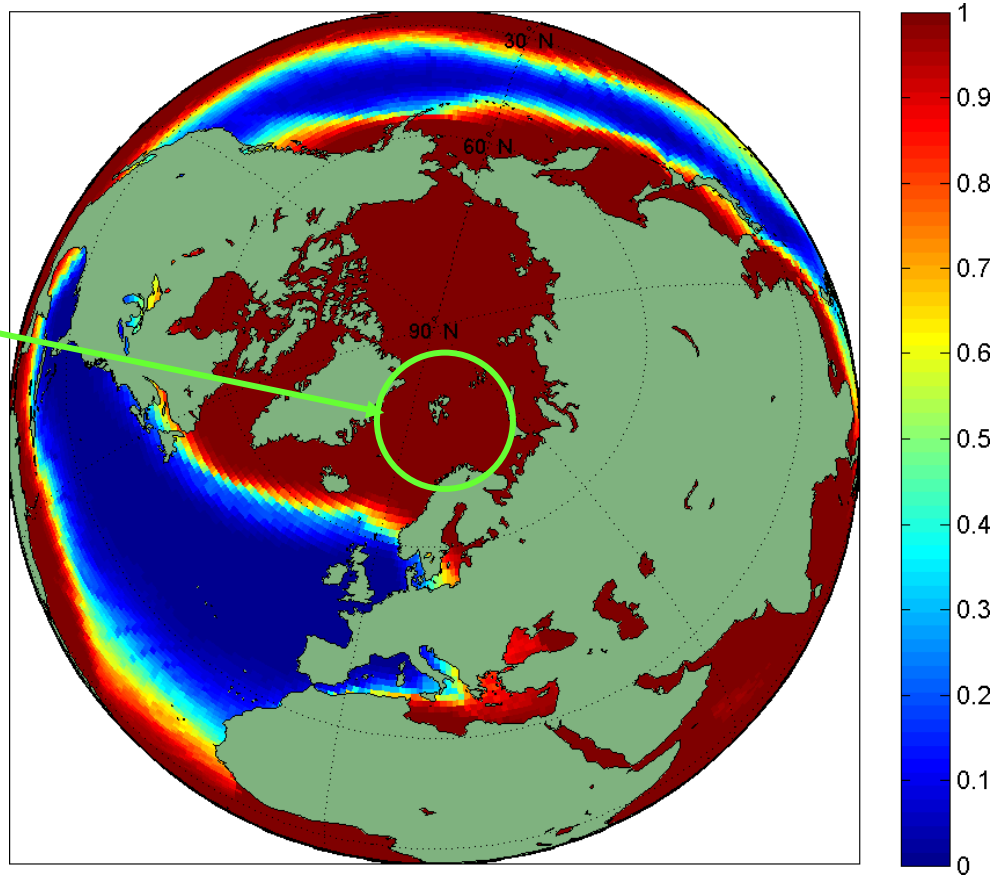


Ideal horizontal dipole

Horizontal dipole with Faraday & Polarization

Global AIS Detection Probability Map

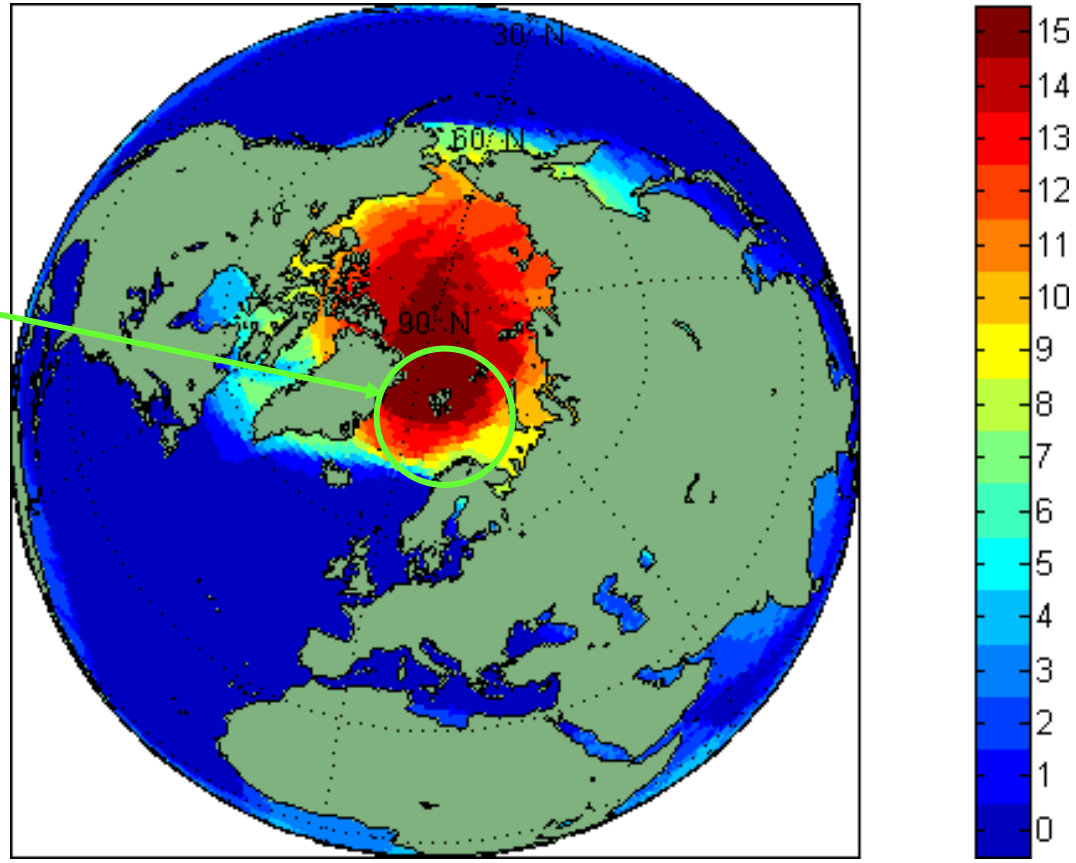
The Norwegian High North



Daily detection probability for 1 satellite in a 600km polar orbit

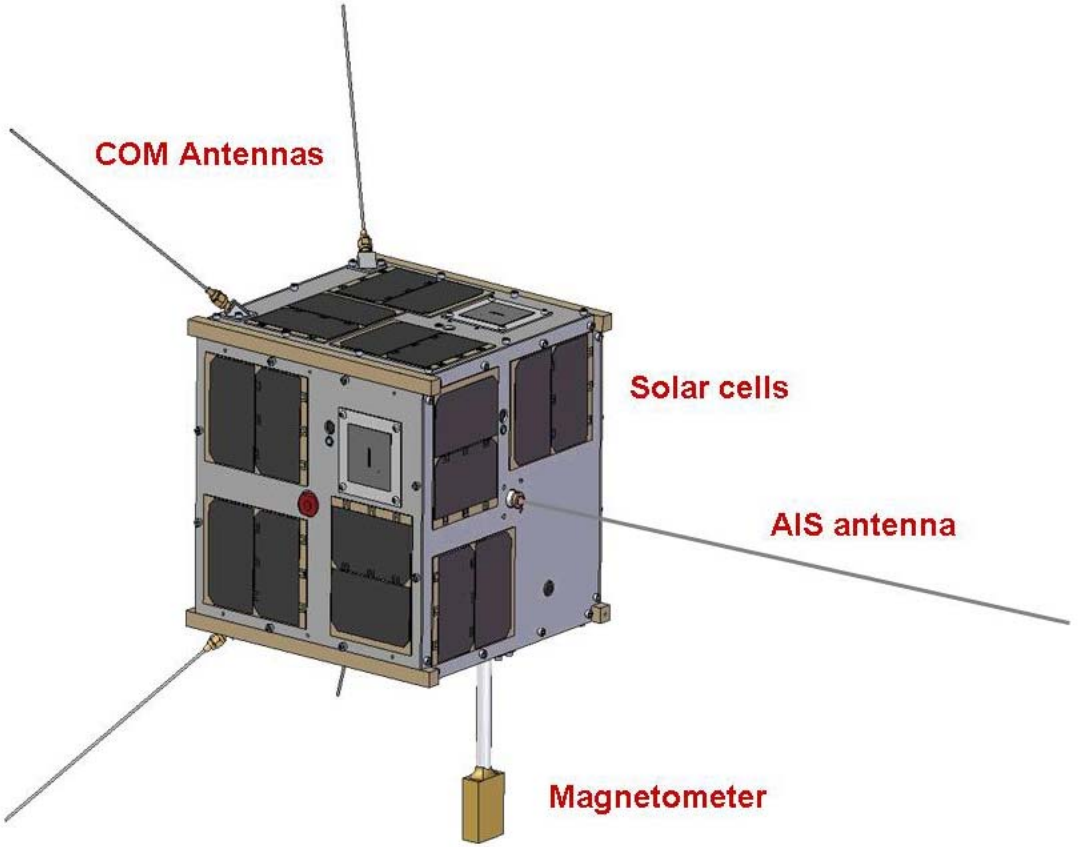
AISSat-1 Daily Observations

The Norwegian High North



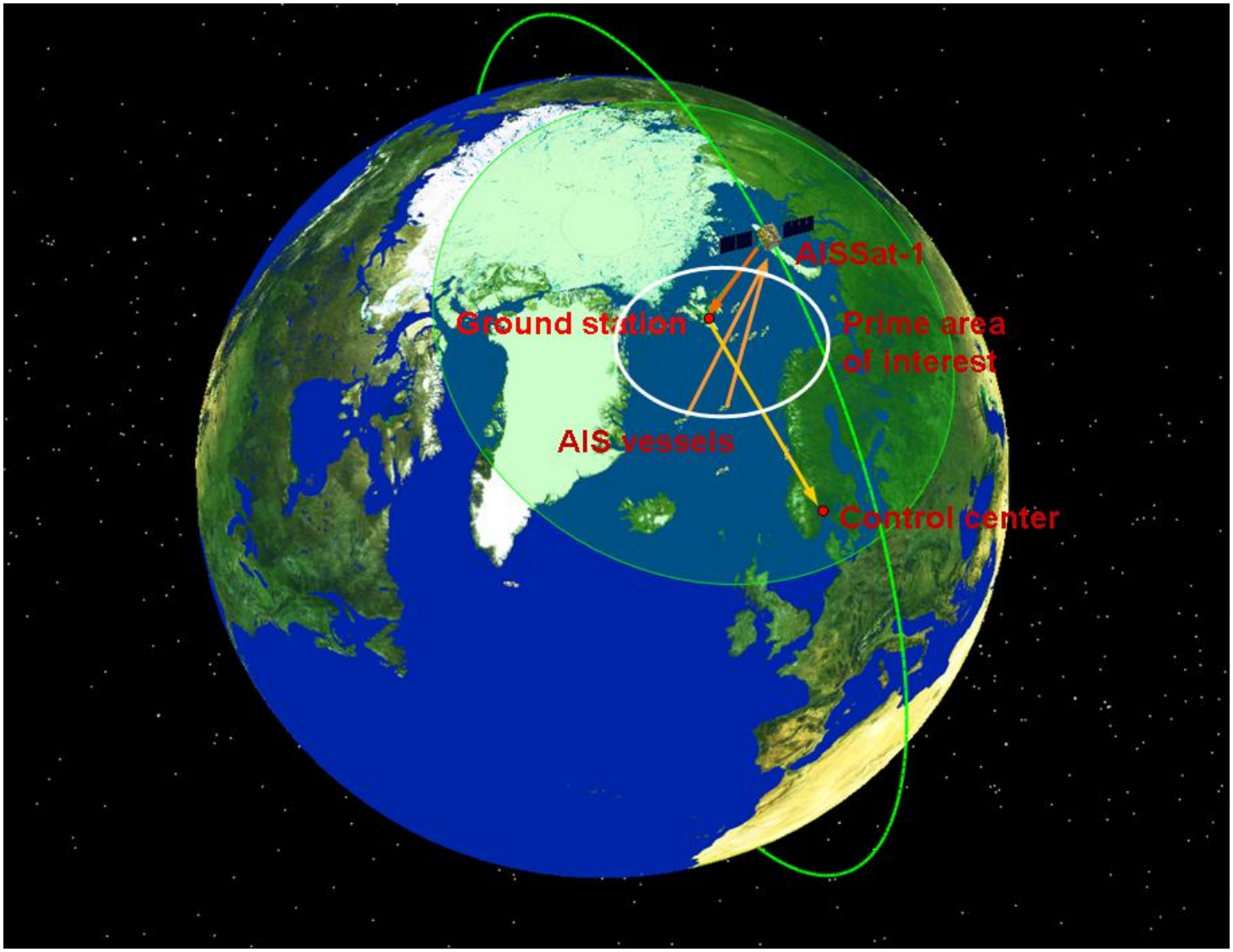
Number of daily observations at >95% detection probability for 1 satellite in a 600km polar orbit

The AISSat-1 Satellite



20x20x20cm, 6.5kg, 5.5W
Polar circular orbit at 600-700km altitude
Designed by Space Flight Laboratory at UTIAS, Canada
AIS Sensor is developed by Kongsberg Seatex

AISSat-1 Mission Architecture



AIS Data Distribution to the Authorities

- Focus on AIS message types 1, 2 and 3

- AIS message as NMEA sentence (ref. IEC-62320-1)
- ”Comment Block” for observation time

Time in Comment Block plus NMEA AIS Sentence:
\1G1:2345,c:1203089309*XX\!AIVDM,1,1,,A,13u?eV001l0kwwRQFiE<7Id f08=V,0*34<CR/LF>

Time and Message Grouped:
\1G3:1234,c:1203089309*XX\<CR/LF>
\2G3:1234*XX\!AIVDM,2,1,4,A,53onnb02;v40h4lGD00<hU10E:1HTdTpL0 00001D02B0D4p10?Tm1CUAlmCQ,0*5E<CR/LF>
\3G3:1234*XX\!AIVDM,2,2,4,A,00000000000,2*20<CR/LF>

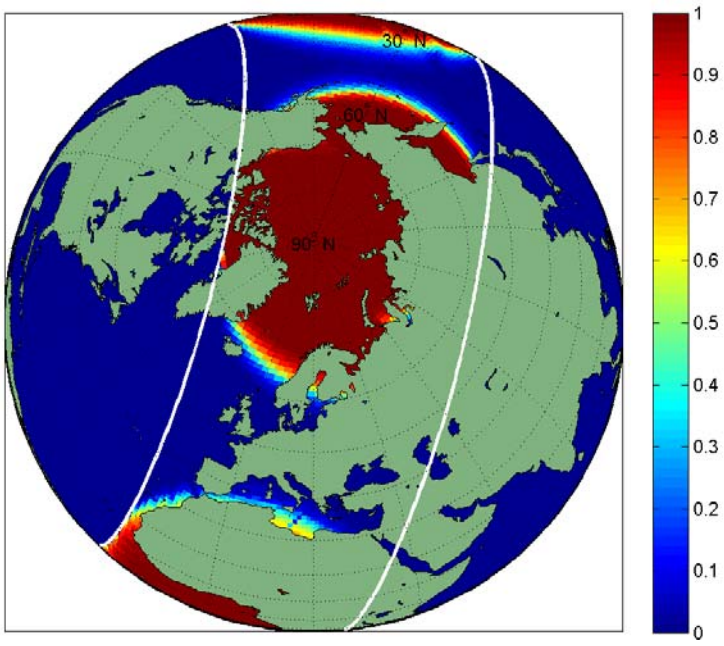
- **Your views are highly appreciated !**

A 3rd Frequency for space-based AIS

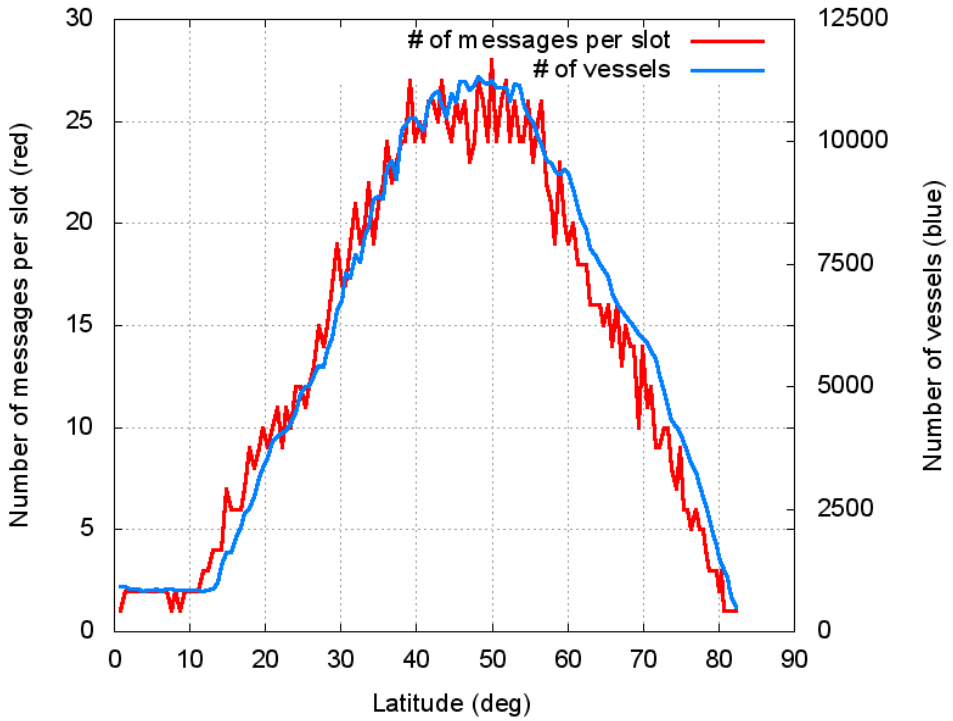
- Presented by FFI at COMSAR-9 February 2005 in London
  - Introduced for Class-A vessels only
  - Transmit only outside base station coverage
  - Short AIS message to eliminate propagation delay
  - 3 min. reporting interval to lower message rate

- Vessel consequences:
  - No extra hardware
  - Transponder software upgrade

Single Timeslot Collision Rate “AIS as is”

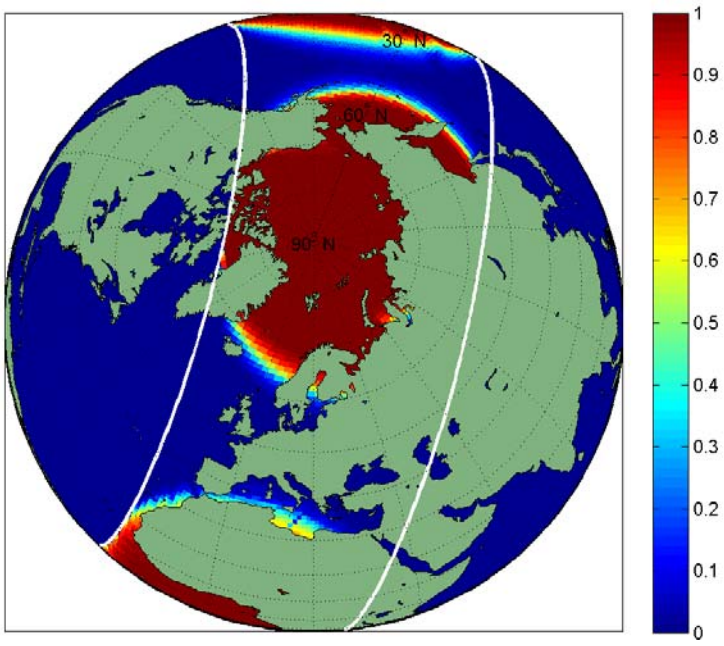


600 km altitude orbit

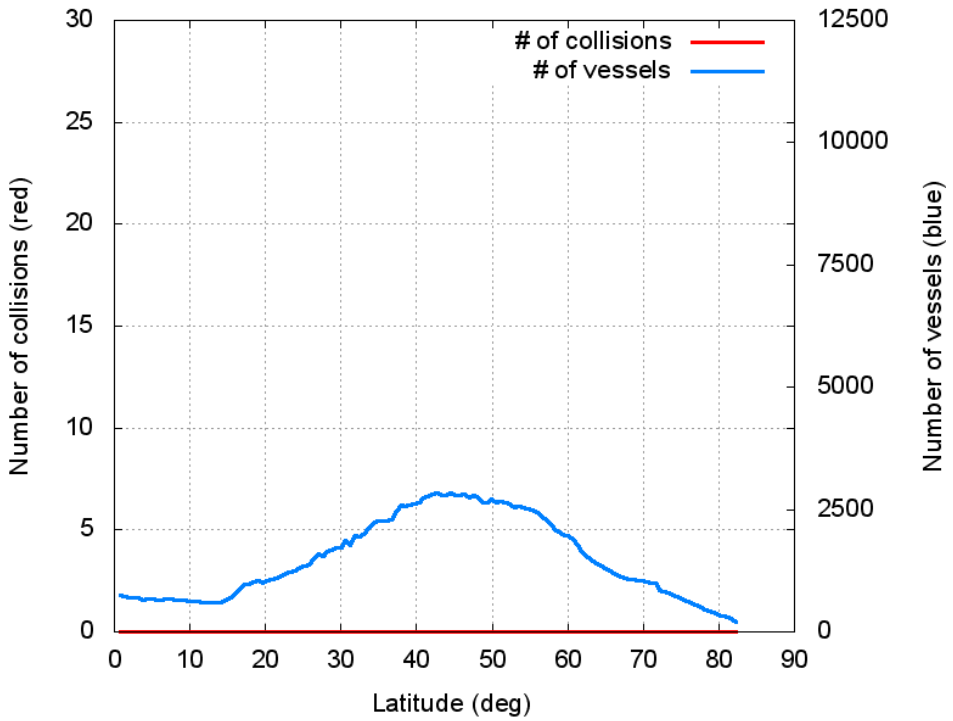


Double timeslot collisions will increase the collision rate

3rd Frequency Collision Rate

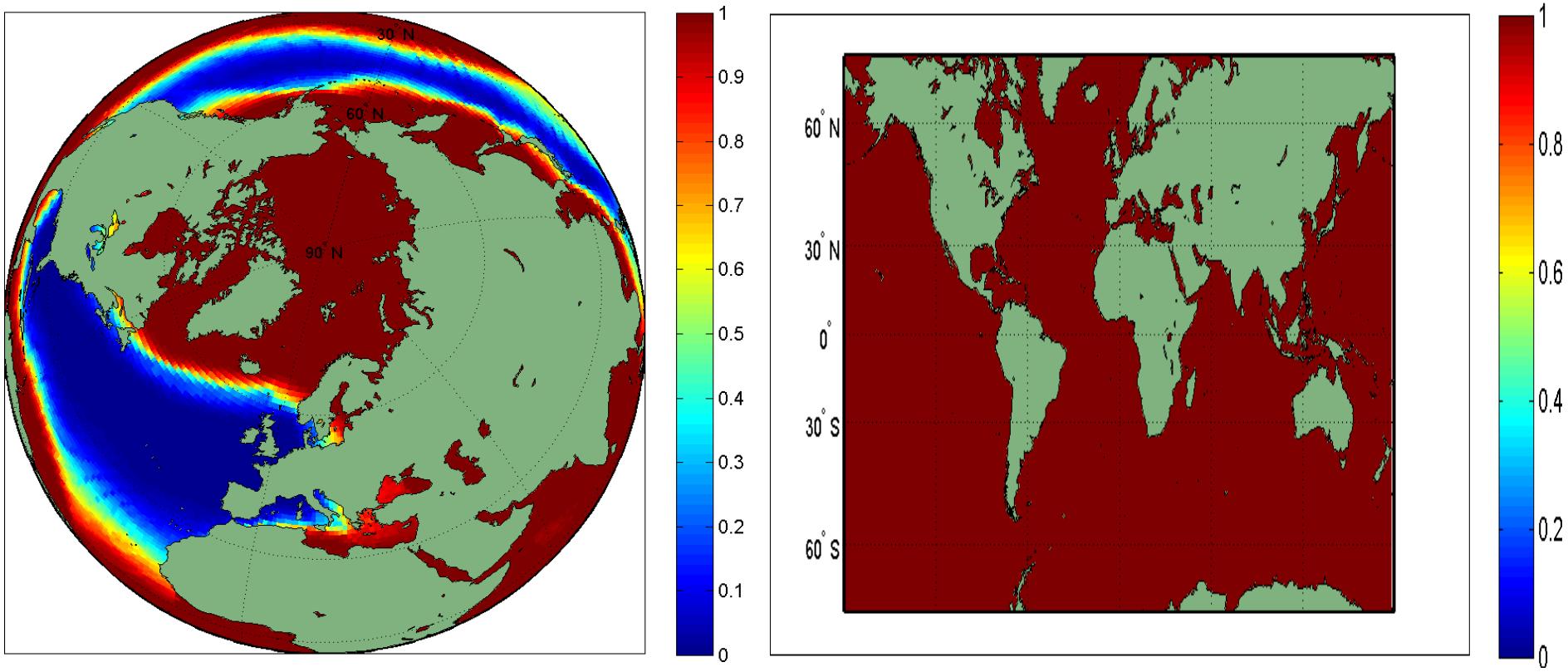


600 km altitude orbit



3 min message interval, Costal traffic removed

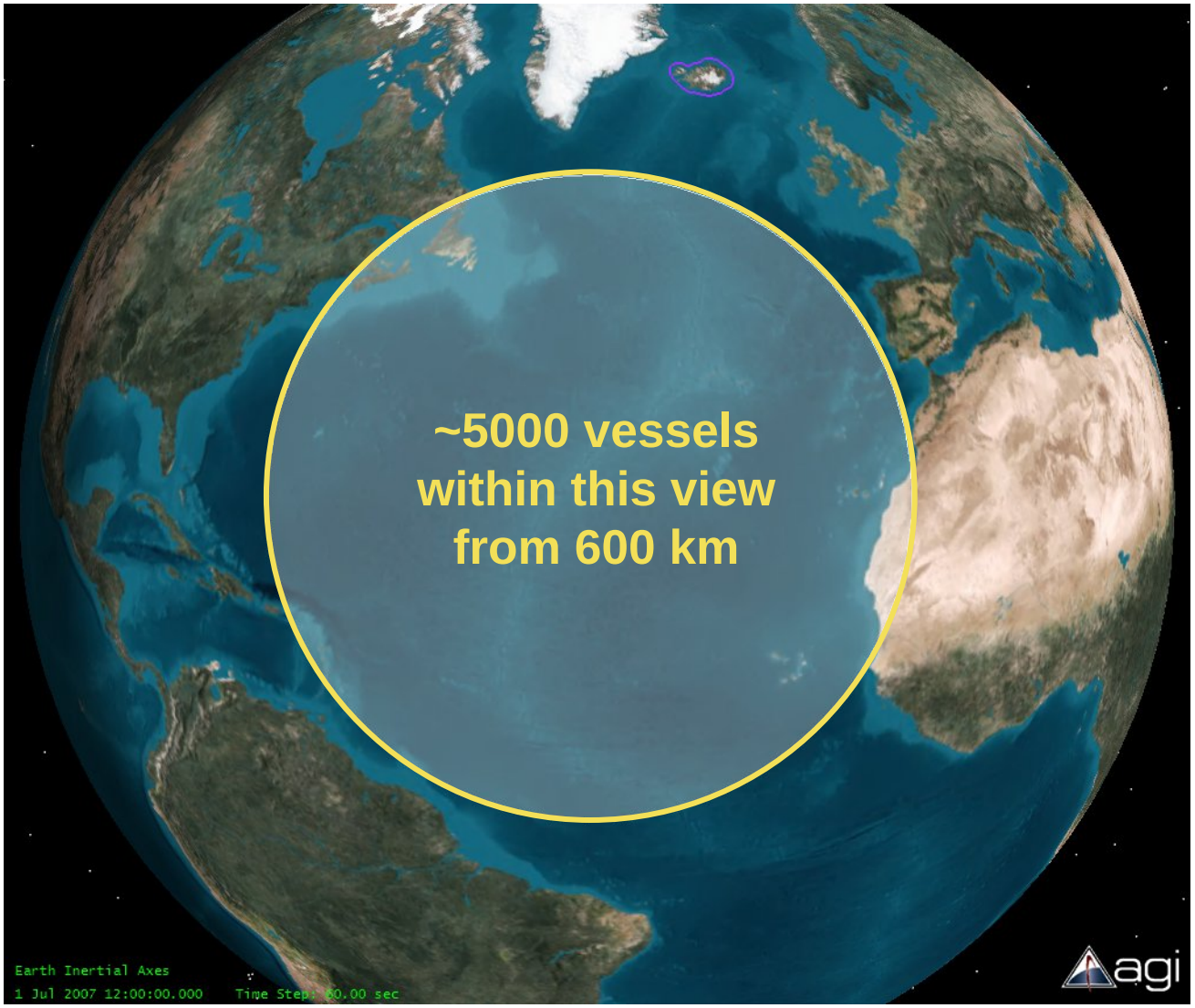
Daily Space-based AIS Detection Probability



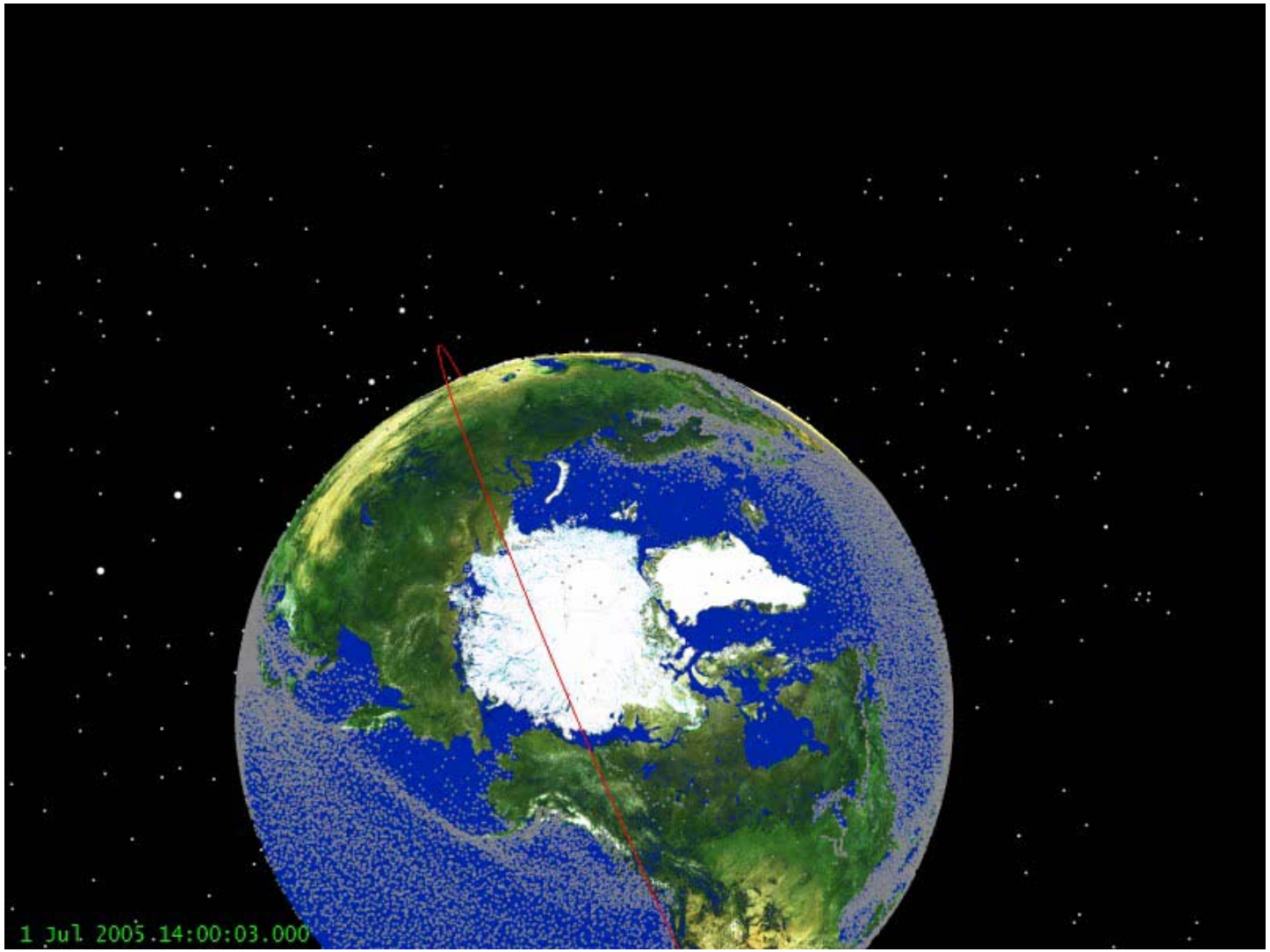
“AIS as is”

3rd frequency

Vessels in the North Atlantic Ocean



AISSat-1 Observation simulation



Monitoring AIS from Space

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